Examples of the level of possible questions for FYTN10 in the oral exam

2  The Klein-Gordon Field

2.1  The necessity of the field viewpoint

- Why do we need to use quantum field theory to describe high energy reactions

2.2  Elements of classical field theory

- What is the principle used for deriving the Euler-Lagrange equation of motion
- Give some examples of symmetries and the related conserved Noether charges

2.3  The Klein-Gordon field as harmonic oscillators

- What is the canonical commutation relation for scalar fields and their conjugate momenta
- What is the basic commutation relation for creation and annihilation operators for scalar fields
- How is the scalar field quantized in Schrödinger and Heisenberg picture
- What is normal ordering and what does it correspond to physically
- What are the eigenstates (one-particle, two-particle etc) of the quantized scalar field
- What is the Lagrangian of the Klein-Gordon field

2.4  The Klein-Gordon field in space-time

- What does it mean that the fields at two points with a spacelike separation commutes and how is this related to causality
- What is the physical interpretation of the Feynman propagator for the scalar field

3  The Dirac Field

3.1  Lorentz invariance in wave equations

- Why do we demand that our theories should be Lorentz covariant
3.2 The Dirac equation

- What does it mean that the Dirac spinor is a spin 1/2 representation of the Lorentz group
- What are the Lorentz transformations on Dirac spinors, $\Lambda_{\frac{1}{2}}$
- What is the Lagrangian of the Dirac field
- What are the left- and right-handed Weyl spinors

3.3 Free particle solutions of the Dirac equation

- What is the relation between the “spin” of a (anti-)fermion and the spinor
- What is relevance of the helicity operator for high energy particles
- What is the relation between helicities of particles and spinors for antifermions
- How does the Dirac spinor look in momentum space for a particle at rest and in the massless limit

3.4 Dirac matrices and Dirac field bilinears

- What is the physical relevance of bilinears

3.5 Quantization of the Dirac field

- How is the Dirac field quantized
- What are the states of the quantized Dirac field
- What is the relation between the quantization condition and the type of statistics fulfilled by the states
- What are the anti-commutation relations for the creation and annihilation operators
- What is the Feynman propagator for the Dirac field
- How can the anti-commutation of Dirac fields be reconciled with causality

3.6 Discrete symmetries of the Dirac theory

- What is the meaning of parity, charge conjugation, and time-reversal symmetries
4 Interacting Fields and Feynman Diagrams

4.1 Perturbation theory - philosophy and examples
- What is the basic assumption underlying perturbation theory
- What is the relation between the interaction Hamiltonian and interaction Lagrangian

4.2 Perturbation expansion of correlation functions
- How is the interaction picture defined and why is it useful
- What is the physical meaning of the time-evolution operator in the interaction picture as a time-ordered exponential

4.3 Wick’s theorem
- How can a time ordered product be rewritten as a sum of normal ordered products and contractions
- What is the physical meaning of contractions between two fields and between a field and an external particle

4.4 Feynman diagrams
- Why are symmetry factors needed

4.5 Cross-sections and the S-matrix
- What is the physical interpretation of a cross-section and a decay width
- How is the S-matrix related to the invariant matrix-element $M$

4.6 Computing S-matrix elements from Feynman diagrams
- How can the $T$-matrix be obtained from the time-ordered exponential of the interaction Hamiltonian
- What is the physical meaning of requiring diagrams to be connected and amputated
- What are the Feynman rules in momentum space for $\lambda \phi^4$ theory
- What is the relation between the Feynman rules in momentum and ordinary space
- Where does the momentum conservation rule come from and why should one integrate over undetermined momenta
4.7 Feynman rules for fermions
  • What are the Feynman rules in momentum space for Yukawa theory
  • How can one find the sign of an amplitude involving fermion fields
  • What is the amplitude and decay width for a scalar decaying into a fermion-antifermion pair

4.8 Feynman rules for quantum electrodynamics
  • What are the Feynman rules in momentum space for QED

5 Elementary Processes of Quantum Electrodynamics

5.1 $e^+e^- \rightarrow \mu^+\mu^-$: introduction
  • What is the corresponding expression in momentum space for a current $\bar{\psi} \gamma^\mu \psi$
  • What is the square of such a current
  • How can the squared matrix element be calculated using trace technology

5.2 $e^+e^- \rightarrow \mu^+\mu^-$: helicity structure
  • How do different helicity combinations contribute to the cross-section
  • How can explicit spinors be used to calculate scattering amplitudes

5.3 $e^+e^- \rightarrow \mu^+\mu^-$: non-relativistic limit
  • What is the non-relativistic limit of a Dirac spinor

5.4 Crossing symmetry
  • How can crossing symmetry be used to relate cross-sections for different scattering processes to each other
  • What is the meaning of the different Mandelstam variables and how are the related to the propagator structure of different types of scattering processes
5.5 Compton scattering
- What are the conditions on the polarisation vector for a physical photon
- How can polarisation sums for external photons be computed
- What is the Ward identity

6 Radiative corrections

6.1 Soft bremsstrahlung
- How is a next-to-leading order cross-section defined diagramatically and why has bremsstrahlung to be included
- What are the Feynman diagrams for bremsstrahlung and the corresponding mathematical expressions
- How is the formula for soft bremsstrahlung derived
- In what directions are the bremsstrahlung photons mainly emitted
- What is the origin of the infrared divergence and how can it be regulated

6.2 The electron vertex function: formal structure
- What Feynman diagrams contribute to the electron-photon vertex and what are the corresponding mathematical expressions from the Feynman rules
- What is the meaning of the form factors $F_1$ and $F_2$ and why are there only two of them

6.3 The electron vertex function: evaluation
- What is the origin of the ultraviolet divergence and how can it be regulated
- What type of diagrams cancel the ultraviolet divergence from the vertex in QED

6.4 The electron vertex function: infrared divergence
- What is the origin of the infrared divergence and how can it be regulated

6.5 Summation and interpretation of infrared divergences
- What is the Sudakov double logarithm and how does it arise
- What is the physical meaning of the Sudakov form factor